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ABSTRACT

This study of the applications of microelectronic devices in industry, together with an assessment of their value for use in schools, emphasizes the basic principles underlying the new technology and the practical ways in which these can contribute to associated work in computing and other disciplines in the school curriculum. Following a description of general issues relating to Scotland, the microchip, and the school, projects simulating industrial processes are described in detail, e.g., projects involving only a microcomputer (stock control system, production line monitoring, setting out road curves); applications using stepping motors (model of numerically-controlled lathe, model "milling machine," model graph plotter, computer-controlled robot arm, general duties, small model of production line); projects using analog-digital interfaces; projects using simple switches (using microcomputers as a counter, traffic light control, production monitor for using individual operator switches); and implementation of simple switch experiments. The report concludes with comments on a few aspects of the new technology and descriptions of stepping motors and their operation, input and output switch signals, and analog conversion. (LMM)

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EDUCATION FOR THE INDUSTRIAL SOCIETY PROJECT

Microelectronic Technology Group

SECONDARY SCHOOL PROJECTS AND THE MICROCHIP

by

A F Irvine

MARCH 1982

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EDUCATION FOR THE INDUSTRIAL SOCIETY PROJECT

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EDUCATION FOR THE INDUSTRIAL SOCIETY PROJECT

1977 - 1982

Remit of Project Planning Committee

"To review the arrangements which secondary education and the secondary schools make to prepare pupils for life and work in an industrial society; to consider what changes and innovations might be made in current practices, curricula and courses to make them more effective; to conduct pilot experiments as appropriate; to evaluate the project; to liaise as appropriate with other elements of the CCC's substructure; and to report to the CCC. "

PREFACE

This Report has been prepared under the auspices of the Microelectronic Technology Group set up by the Planning Committee of the Education for the Industrial Society Project. The Committee is charged with considering "what changes and innovations might be made in current practices, curricula and courses to make them more effective". In this connection the Committee has been encouraged by the Consultative Committee on the Curriculum (CCC)* to maintain a considerable degree of independence in thought and action. The present Report should be read against that background.

The recommendations of the Group will be considered by the appropriate committees within the CCC structure. Account will be taken of other views. In this connection the CCC will welcome comments from recipients of the Report. These should be addressed to the Secretary, Consultative Committee on the Curriculum, New St Andrew's House, Edinburgh, EH1 3SY.

* *The Consultative Committee on the Curriculum is the main advisory body to the Secretary of State for Scotland on the curriculum in Scottish schools.*

FOREWORD

Microelectronic technology has already brought about great changes in our industrial society and there can be little doubt that it will bring about even more changes. The study and use of this technology must be developed in our schools, and part of this study must seek to increase understanding of how microelectronic technology is used in industry.

The Education for the Industrial Society Project's Microelectronic Technology Group has been looking at this problem and Mr A F Irvine's report is a fascinating study of the applications of microelectronic devices in industry together with an assessment of their value for use in schools. Projects simulating industrial processes are described in detail.

Mr A F Irvine, who is now retired, was formerly Senior Lecturer in Computing in the Department of Mathematics and Computing at Paisley Technical College.

The Education for the Industrial Society Project welcomes the report as an important contribution to its work. The Project gladly acknowledges the help provided by the Scottish Economic Planning Department.

D J White
Chairman
Project Planning Committee

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ACKNOWLEDGEMENT

Working on this Report has been an enjoyable experience, not least due to the contacts which were made with teachers and with staff in industry. They gave generously of their time and the discussions which took place and the advice given were most useful in the writing of the Report.

Chapter 2 describes some projects in depth. These are provided as stimulus material for teachers: it should be emphasised that they have not been tested in the classroom.

A F IRVINE.

FIRMS CONTACTED

Firms Visited

Hughes Electronics, Glenrothes (dedicated microchips)

Bram International, Galashiels (production monitors and other devices)

Barr and Stroud, Glasgow (scientific instruments)

Airamco, Kilwinning (robust type of microcomputers)

Sangamo-Weston, Port Glasgow (metering equipment)

Strathclyde Police, Glasgow (traffic systems)

National Semiconductor, Greenock (makers of microchips)

Ferranti, Edinburgh (scientific instruments)

Firms Sending Information

Veeder-Roote, Dundee (industrial counters)

National Cash Register, Dundee (computing equipment)

Denyer-Waimsley Micro-Electronics, Edinburgh (printed circuits)

Balray (Photo-tools), Selkirk (printed circuits)

In addition, a visit was made to the Industrial Exhibition (Kelvin Hall) where many applications of micro-electronics in industry were on show. Some obvious candidates for industrial visits, eg IBM and DEC, were not visited because of previous knowledge of their work in other contexts.

SCHOOLS CONTACTED

Ainslie Park High School (Edinburgh)

Banchory Academy

Bishopbriggs High School

Carnoustie High School

Craigie High School (Dundee)

Craigshill High School (Livingston)

Duncanrig High School (East Kilbride)

Elgin High School

Garnock Academy

Larkhall Academy

Mackie Academy (Stonehaven)

Musselburgh Grammar School

Oban High School

Portobello High School

Portree High School

Stranraer Academy

CHAPTER 1 : SCOTLAND, THE MICROCHIP AND SCHOOL

1. INTRODUCTION

This Report stems from a grant by the Scottish Economic Planning Department to the Education for the Industrial Society Project which enabled a Development Officer to be seconded to the Microelectronic Technology Group for the period September 1980 - September 1981.

The remit of the Development Officer was to survey current uses in industry in Scotland of aspects of microelectronic technology with particular regard to identifying elements of the new technology which might be of value to schools. The work of the Development Officer therefore complements that of the Group noted in the report Microcomputers and the Secondary School, March 1982.

The Development Officer visited a number of industries in Scotland and in March 1981 prepared a brief working paper for schools reporting on progress to date. This led to an exchange of information and ideas with teachers who had experience of the field and these contacts were most valuable in the writing of this final Report to the Project Planning Committee.

The purpose of the Report is to provide some background information to schools on the types of industries which are being influenced by the new technology and also on some aspects of that technology which might be considered appropriate for development in schools. It must be emphasised that the technology has developed rapidly in the past and it is likely to develop just as rapidly in the future. Particular emphasis therefore is given in the Report to the basic principles underlying the new technology and to the practical way these can contribute to associated work in computing and other disciplines in the school curriculum.

There is great variety in the way in which microelectronic devices are designed, developed and used in industry. The Development Officer has been impressed by personal qualities of initiative shown by many of the people working with this new technology in industry and by the fact that its successful implementation almost always requires narrow subject boundaries to be crossed. These are major factors which one hopes will not be lost sight of when aspects of microelectronics are introduced into the school curriculum.

Chapter 2 describes some typical processes in industry which, it is hoped, will provide some ideas for the introduction into schools of aspects of the new technology. These are probably of perhaps most immediate relevance to work in physics and technical departments in schools. However, wider aspects are relevant and may be of interest to teachers in, eg, science, mathematics, economics and business studies. The main purpose of the example chosen is to provide some information on how the new technology is applied in industry. Some of the projects can be set up with little difficulty: others however require a great deal of thought before they can be satisfactorily set up and teachers should be aware of this. The Report concludes with a brief overview in Chapter 3 of some of the technical elements of the new technology.

2. INDUSTRY AND THE MICROCHIP

Since the coming of the computer era and transistor electronics, Scotland

has been well represented in the manufacture of computers and electronic equipment despite the fact that the major user markets were elsewhere. Initially, the main impetus for this activity came from overseas companies. The trend is changing and today there are many instances of local initiatives which have led to the development of successful firms with new ideas for products and good strategies for marketing them.

The coming of the microchip has created a revolution in existing industry and has given rise to enormous opportunities for new applications of microelectronic devices where small size, cheapness and dependability are crucial. Among the other advantages of the microchip are its speed of operation - faster than any of the mechanical devices it controls - its ability to take account of a great many variables (temperature, pressure etc as well as time) and do elaborate calculations using these variables before operating accordingly, and, its ability to be programmed and indeed to 'learn' from experience.

The industries which are involved with some aspect of microelectronics can be roughly classified as those which make microchips, those which manufacture computers and other high technology devices and those which use the products of the specialist firms to assist in the production of their particular products. The latter are by far the most numerous and will almost certainly increase in number and variety.

Manufacturers of Microchips

A number of firms, eg National Semiconductor and Hughes Electronics make the fundamental devices of the new technology. Such firms make 'dedicated' chips which are permanently programmed for one specific task. These firms and others at the forefront of the new technologies have to train their workers in entirely new skills which involve the use of delicate equipment - jobs which are not in the traditional list of trade classifications. Graduates in electronics are employed as are skilled electronic technicians. A large number of trained support staff are also required for such manipulative skills as plating, etching and testing.

It might be thought that management would be content to train the operative and let him or her carry on doing that job. In fact, management would be happier to have a higher proportion of workers with the necessary technical interest to study and acquire a broader knowledge of the industry and so move into even more responsible jobs. There are good opportunities for school leavers with 'O' grades in mathematics and science who are keen to take on a routine but skilled job and study for promotion.

Manufacturers of Microcomputers and Other User Devices

There are a few microcomputer manufacturers in Scotland and a large number of firms making devices which are almost entirely electronic in character ranging from weighing machines to process monitors.

In the main the assembly industries are engaged in designing and putting together microchips made elsewhere, usually with standard keyboards and other parts. Their success depends on getting the correct combination from the multitude of standard devices available to satisfy the customers' needs at an attractive price. Because of this assembly requirement most of the work force are engaged in routine, though manipulatively skilled tasks. Expertise is also required at the design stage and in sales and customer maintenance and also, of course, in management. Although some of the companies and much of the expertise originated elsewhere, there

are some cases of local enterprise creating a microelectronics product which is able to sell even in California, the home of the microchip.

The potential for growth in this field seems very great, given a supply of enterprising and well-motivated people.

Firms using Microelectronics in their Production Lines

(a) Production Control

Microelectronic devices can be used to control complete production processes. This technique is particularly useful where a number of variable factors, for example, temperature, humidity, water flow, have to be controlled or allowed for in the operation and very precise timing and counting operations are possible. Metering can be centralised at a computer terminal instead of being personally supervised by an operator - ie, the computer can look out for undesirable changes in the operation and take automatic action to rectify matters. Operator intervention is only required when a change in operation is desired, eg, to speed up or slow down the production line. Information of all kinds is more and more being converted to digital form for display on the familiar Visual Display Unit screen. Pressures, temperatures, flow rates, etc, are all measured or controlled by microelectronic devices with increasing accuracy and reliability, and such measurements may be fed directly into a computer to monitor or control specific instruments in the production process.

(b) Manufacture of Instruments

Scotland has now many firms making equipment for defence and other purposes (eg, Ferranti, Barr & Stroud) which are necessarily concerned with microelectronic devices and employ people trained to the highest levels in microelectronic engineering. There are also smaller firms making, for example, counters, which, although not themselves necessarily highly skilled in all aspects of microelectronics, use products from microelectronic companies for digital display and counting purposes in their own goods.

(c) Computer Aided Manufacture (CAM)

This is a general term for the techniques used in the computer control of machine tools (usually known as N/C or Numerical Control). Such techniques were actually pioneered in Scotland by Ferranti in the 1950s but are only now becoming general in the engineering industry, and usually, with machinery from overseas. CAM is probably the most important aspect of microelectronics in its impact on manufacture and employment. A computer controlled lathe, for example, can turn out highly accurate work about three times as fast as a similar machine operated by a human operator and is not subject to human errors. The accuracy is extremely high since the machine will faithfully follow predetermined curves to an accuracy limited only by the tool used and vibration. The necessary accuracy is currently about one thousandth of a millimetre.

The progress of CAM has been held up by two factors

the high cost of computers in former years, requiring usually a large computer to produce controlling tapes for a large number of machines, and

the need to re-train operators in the new skills.

The first difficulty is now removed since reasonably cheap and reliable microcomputers are available with sufficient fast store capacity to translate the high-level user instructions into machine operating code. So much so that it is quite usual to have a microcomputer attached to a single machine tool.

To produce a new part on an N/C machine one first writes a program in a high-level language, eg APT, SCS which describes the part to be produced in exact geometric terms. The computer than translates this by a processor program (sometimes followed by a 'post processor' program) into the code for controlling that machine tool. This can either be output as magnetic or paper tape for controlling the machine, or go directly to the machine. The machine has a controller unit (which is really a small computer) which translates the code into actual movements of the machine, ie, the exact distance to move in the X, Y and Z directions. Both the computer and the controller can now be made small and are inexpensive. In fact the controller can be a single chip. The machines can be lathes, jigborers, milling machines, arc cutting or welding machines, or, in fact, any machine where the operating tool has to move precisely and in a prescribed manner.

The impact of CAM is such that it is difficult to envisage much future for the long lines of manually operated machines where human beings simply repeat routine movements, or even for the highly skilled operator working on high precision, individual work. It is easier to write and test a program than to re-tool with new jigs and cams. The programs can be stored indefinitely for future use and it is quite simple to modify them if this is necessary.

3. THE PREPARATION OF THE SCHOOL LEAVER

The expansion of manufacturing industries using the new technology and the potential explosion of industrial applications of the microchip are causing a substantial change in the nature of industrial society. It is timely, therefore, to comment on these changes with regard to the implications for schools and the education and preparation of pupils.

The work now being done with microcomputers, used in the 'classical' way as calculation and file handlers, is making a fine start on one aspect of the problem. The other aspect of using microelectronic devices in instrumentation and control, is, with the notable exception of a few isolated enthusiasts, not being tackled. General strategies should be evolved to familiarise the pupils with the use of microelectonic devices as tools to be used; pupils need to be given some insight into the highly automated industrial world they will enter and its relation to the current technology.

The objectives of teaching aspects of microelectronics at school include those which are given below with comment.

(a) A general appreciation of what microelectronic devices can do, with some emphasis on removing the mystery and 'black-box' character of the devices.

For most pupils, a precise understanding of the actual operation of the equipment and associated theory is probably unnecessary.

The initiative of teachers and of the pupils themselves can make a significant contribution to this process of familiarisation. For example, if the device was known to be designed and constructed in school by teachers and senior pupils using school-based materials, it would not have the same degree of mystery when used by younger pupils, but would be something their elder contemporaries had developed and which, in due course, they might further develop.

(b) Some insight into the use of microelectronic devices in industry and the careers emanating from their use.

In this role, technical departments would seem to have a crucial responsibility. Unfortunately these departments, with a few exceptions, appear to have been largely left out of the microcomputer developments in schools. Staff in technical departments need to be recognised as key personnel in microelectronics education and their in-service requirements need to be re-examined in this light. When one considers that future technicians will be largely employed in testing and repairing electronic equipment, possibly in conjunction with mechanical repairs, it would seem to be an area of some importance.

As a first step, courses are needed specifically to introduce technical teachers to the new techniques. These could be similar to the courses for engineering technicians and technologists being developed at the Microelectronics Educational Development Centre at Paisley where scale models of industrial rigs and processes are available. It is important that technical teachers are introduced to these developments by people who have practical engineering experience.

It would also be helpful if science and technical staff co-operated, as the former will probably have had more formal training in electrical devices. The combination of electronic knowledge and technical skill could be very fruitful and indeed, is probably necessary for the sensible introduction into schools of suitable aspects of microelectronic technology.

(c) Knowledge of the use of some of the items in the huge variety of equipment used in microelectronics - adders, decoders, opto-devices, thermistors, strain gauges etc.

These devices are the future tools of the school science laboratory as they are of the present university and industrial laboratories. Their relatively low cost and ready availability should help in making it possible for schools to acquire them. Although detailed notes on their use can often be obtained on request when orders are placed, it would be sensible for such information and advice to be provided to schools from a national and centralised source.

(d) Stimulation of pupils with good practical ability and academic background to tackle post-school courses in microelectronics.

The industrial future of the country depends on the flow of bright young men and women entering this field with enthusiasm. It is a field where women are at no disadvantage as the new industries are far removed from the noisy and dirty environment of the older industries.

The new technology uses skills and expertise drawn from a variety of subject areas, eg, technical, science, mathematics, economics and business studies,

in addition to those implicit within computing itself. Staff in such disciplines should be encouraged to seek out the relevant aspects of the new technology so that curriculum changes can be introduced as appropriate.

4. PROJECTS

One way to stimulate senior pupils - assuming they have a good grasp of mathematics and physics - is to encourage them to do projects which involve interfacing microcomputers with, for example, stepping motors, relays, analog-digital converters. If projects are chosen to result in a demonstration model which can be used to stimulate younger pupils as mentioned under 3(a) and 3(d), the value of the project is greatly multiplied. Projects should be supervised jointly by the staff in physics and technical departments and involve other expertise as necessary. Some suggestions for projects are made in Chapter 2.

The ideal project would be one which

- interfaces a computer to a model which illustrates the working of some industrial process, so that the computer commands control the process,
- uses only inexpensive devices such as are available from radio surplus dealers or laboratory suppliers and mechanical parts from Meccano or the school workshop, and
- is suitable for demonstration purposes to younger pupils, with no assembly required other than connection to the computer.

It is highly desirable that staff who use a computer for interfacing work learn a good deal about the particular machine they are using. For some of this work it is useful to know something of the assembler (low level) language of the machine. Ideally one should gain experience of using the microcomputer as a control tool by using it for some simple operations to get the feel of the equipment and gain confidence in it. Suggested initial experiments might include

- using the microcomputer with an analog-digital interface as a digitial voltmeter,
- using the computer as a time device for, say, a Fletcher's trolley experiment,
- using the computer as a counter by inputting a pulse from a mechanical or optical switch every time an object passes the switch,
- switching on a lamp or a small fan or heater by using a computer instruction to operate a relay.

The last stage would be to assemble the techniques thus mastered into the plan for a complete experiment or industrial model. This is not as simple as it may seem, since the computer has to perform several tasks and may miss, say, a counter pulse if the pulse is too short and occurs while the computer is busy, for example, outputting results. It helps to remember that most experiments seldom work well at the first attempt and those involving microelectronic devices are no different. Confidence in handling the equipment and practical experience are the best guarantees for success.

CHAPTER 2 : PROJECTS SIMULATING INDUSTRIAL PROCESSES

A. PROJECTS INVOLVING ONLY A MICROCOMPUTER

(1) Stock Control System

The objective is to simulate the control of stock input and output as used in all large engineering firms with a computer. Such a firm uses many thousands of different components ranging from small nuts to large tractor wheels. The essential thing about any stock system is to devise a suitable key or index number for each component, chosen in some systematic way, eg all nuts could begin with N, followed by diameter in hundredths of a millimetre, followed by a screw thread descriptive number, giving say N420826. It is essential that every component should have a unique 'number' which indicates its character. To prevent mistakes and make searching and verifying easier the component should have a verbal description attached to it also, eg 'Nuts 4.2mm Aluminium, External Drum Casing Turbine XIV'.

The object of the system is to ensure that an accurate record is immediately available of the stock at any given moment, and to ensure that no item is ever 'out-of-stock' - a whole works can be brought to a stop because one small component is missing! To do this, each item should be accompanied by a 'lead time' indicating how long it takes to order and deliver the item, and a measure of the rate at which the item is being used. Using this information a computer can estimate the point at which new stock must be ordered to prevent an out-of-stock situation. Note that the overstocking of items is also undesirable, as stock is costly and modern industry has to cut down the money tied up to increase its cash flow. The computer can be used to print out orders for new stock, say at the end of each day.

Many other features can be inserted in the system. For example, if a new product is being introduced its components will have to be inserted in the file and estimated rates of usage corrected at intervals until the system settles to steady production.

Programs required: a) Recording new stock; b) Issue of stock; c) Ordering of stock when this is indicated by program b); d) Management summary.

Programs a) and b) are 'on-line', ie they are available when required by the gateman, storeman, etc, and produce a response immediately. In a school situation the same machines can be used for both 'in' and 'out' operations. (This is done in small firms also.) Input or output can be chosen by the operator's first command, eg 1 for input, 2 for output, 3 for ordering, and 4 for summary. Programs c) and d) might be run separately as end-of-the-day routines. The programs a) and b) should take in the code number, description and quantity in the consignment and print out a record of the stock of that item after this transaction. Programs c) and d) would require a teletype or printer but can be simulated on the CRT. A typical item record could have a format as follows:

Item code number (6 characters); Item description (36 characters); Number in stock; Delivery time in days; Total quantity used this year; Rate of use; Minimum stock allowed; Order date; Price per item; Maximum stock; Week number.

The 'total used' is required to calculate the current rate of use, and this is used to compute the time it would take for the stock to run down to the minimum permitted level. When this time nearly equals the 'delivery time' the computer can print an order to bring the stock up to maximum or some prearranged level less than maximum.

A program of this kind can be extended to bring in expertise from various fields:-

(a) Prediction of seasonal variations and incorporating these in the program. (statistics)

(b) Computing of mean and standard deviation of delivery times and the use of these to calculate probabilities of late delivery. (statistics)

(c) Calculation of present value of stock using latest prices typed in at each delivery, and possibly writing off old deteriorated stock. This is important for tax and accounting purposes. (business studies)

(d) Control of radioactive stocks (now fairly common due to the use of such materials in flow testing and smoke detection). The special feature of this kind of stock is that it decays at a known rate and there are Government regulations defining the total activity permitted and the strength below which the materials can be safely disposed of. (science and mathematics)

(e) Incorporate the supplier's name and a 'complaint' scheme so that components found to be frequently at fault can be pinpointed. (business studies)

(2) Production-line Monitoring

In many industries, particularly those involved in piecework or production bonus schemes it is desirable to let individual employees know how their production rate compares with the target set for them, to record their production and estimate their pay to date, and, finally, to indicate to management how production is going and in particular give early indication of material shortage, personnel shortage, etc.

The system (as illustrated by the equipment produced by BRAM in Galashiels) is that each worker, as each task is completed (eg, finishing a garment) presses a switch to indicate this completion and the worker's own screen is updated. The screen shows the number of tasks completed, the number which should be completed by that time for the worker to be on target, and the percentage of the target achieved. It may also show the piecework wage earned up till then. Another switch indicates a hold-up because of material shortage, another personnel shortage (ie, worker due to assist being absent), and other switches, to indicate the end of these states.

In the management area is a master screen showing the various outputs and totals, and giving immediate warning of hold-ups. The system requires a clock built into the system, to give the rate of working.

We could simulate this system using one prominently placed computer and a series of interfaced switches. It would, however, call for more interface channels than could readily be available on most microcomputers, and it is suggested that instead, the operators press different keys on the ordinary keyboard of the machine, thus requiring no interfacing.

Allocate say numbers 1 to 6 for 6 workers, 7 for material hold-up, 8 for personnel hold-up, 9 for clock, 0 for end of hold-up. 10 will give a management display showing totals, total hold-up time etc. The program will revert to normal when 11 is entered. (It could be supposed that management only uses it at teabreaks etc when no other entries are being made.)

Since few of the available microcomputers are fitted with a programmable timing device, we can input the passage of time by one pupil being given the duty of pressing the '9' key exactly every minute. The display of each operator remains on screen and is updated at every input of the operator, except when the management display is called for. All official stoppages for tea and lunch breaks etc, are deducted from the total time by simply not putting in the clock signal during this time.

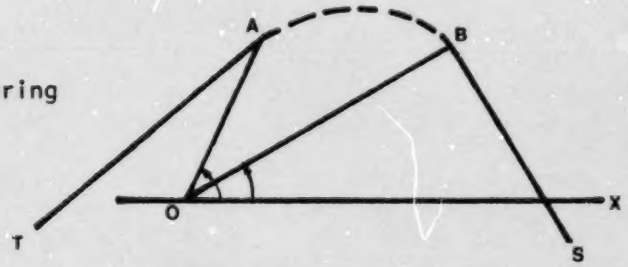
(3) Civil Engineering Application - Setting out of Road Curves (Circular)

When a road curves, the two straight sections on either side of the curve are to be joined by an arc in such a way that there is no abrupt change in direction. A circular arc tangential to the two road lines is often used.

The site engineer has to set out pegs round the curve so that the line of the road is accurately marked. The program gives the bearing and chainage from a fixed point, of each peg position (accurately calculated) given the position of the ends of the straight parts and the directions of the straight parts as measured from a base line.

Fig 1

Civil Engineering



In Fig 1 TA and SB are the straight parts with angles XOA and XOB measured from base line OX.

There are two ways of finding an appropriate arc:

i) find a circular arch touching TA at A and touching SB at some point B

ii) given a radius, find the circle touching both lines at some points A, B.

Lines from O at small angular intervals are then taken and the distances of their intersections with the circle calculated. The set of angles and corresponding distances constitutes the answer table. It is only necessary for the engineer to measure out with his tape or chain at each angle in turn and insert the peg at the calculated distance.

The working out of the program gives a good exercise in practical geometry and the results can be tested on the ground.

NOTE:

1. The obvious 'paper' method of drawing perpendiculars from A and B to find the centre and then drawing the arc with a string is not usually feasible since the centre is normally away off the road line in wild country!

2. An extension of this program to cope with cases where the road is going uphill and curving at the same time is in use in engineering work.

In addition to the three examples described above, two other possible projects which would give teachers some idea of the breadth of applications are noted below.

i) Food processing industry - weighing, mixing, measurement of water content etc.

ii) Petro-chemical industry - virtually an infinite sink in applications and monitoring of temperature, pressures, flow notes, densities, chemical analysis etc.

B. APPLICATIONS USING STEPPING MOTORS

(Stepping Motors are described further in Chapter 3. This section describes some of their applications)

(1) Model of Numerically Controlled Lathe

One of the first applications of computers in industry was in the programming of machine tools, and this is still of great importance.

The 'numerical control' system means that a program in an easily-used high level language can design a product, this program being translated by a computer to a machine-code program for the machine-tool controller circuits, which in turn creates the correct movements to manufacture the part.

The digital devices required are:-

A 'controller' which is really a small computer, and nowadays can be a single microchip. This is considered as part of the

machine-tool system, and takes in digital instruction direct from another computer or from a paper tape or magnetic tape produced by a computer, and sends appropriate orders to the moving parts of the machinery, eg 10 more steps in the X direction and 7 in the Y direction.

A computer of the usual general purpose type which translates a program written in a high level language (eg MELAPT SCS) into the machine code for that particular machine-tool controller.

An example of an instruction for a controller would be:-

G 0102 X 0126400 Y 0012682 Z 0000 R 4000

where G is a general instruction such as 'free all axes', the X, Y and Z figures represent the point to which the tool must next proceed, and the R figure represents the rate of traverse. Units are usually thousandths of a millimetre. The controller simply moves the tool from one point to the next, or in some cases describes a circular arc between two points.

The translation of the higher language requires a large amount of store and high accuracy, which is beyond the powers of the present generation of microcomputers although some firms are attempting to produce some suitable software.

If we have to program directly in controller code we have to work out all the intersections mathematically, and also allow for the tool diameter in our calculations.

This simple kind of program is often used in drilling sets of holes, as there is little calculation involved in this.

The lathe is chosen as an example because it involves only two stepping motors. For safety reasons and because the cheap motors available are not powerful enough, no metal or wood cutting is envisaged but simply a demonstration cutting or turning of soft material like plasticine, wax or packing material.

The benefits of the project are two-fold:

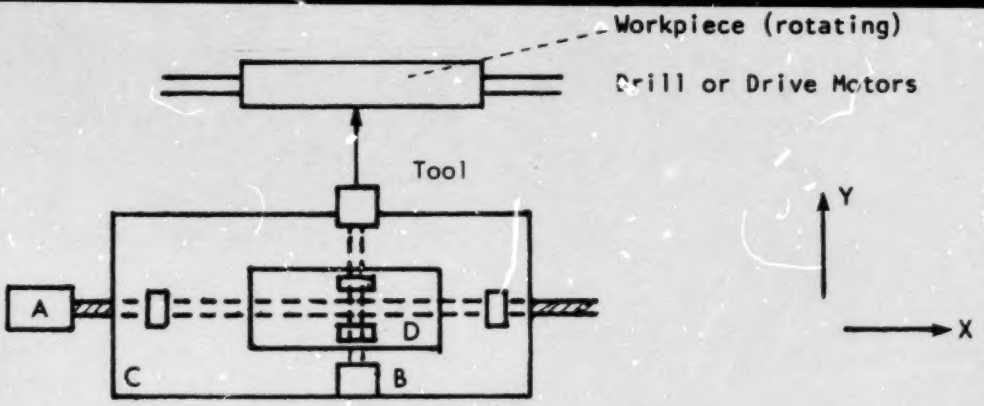
i) The gaining of expertise of sixth-formers in making the model.

ii) The power of the model to demonstrate safely the uses and techniques of numerical control of machine tools.

The Model

One stepping motor A (Fig 2) moves the tool in the X direction along a screw thread and the other, B, moves the tool in and out of the workpiece (Y direction). Each motor must be independently controlled by the computer. In the case of the type tested there are four connections from the motor. One to the negative end of a 12 volt DC supply, one to each of three coils on the motor. These coils are fed from three separate bit channels on the user part of the computer, through a driver unit which may be a standard type of amplifier or a device like a darlington driver.

Fig 2



Simple Lathe Arrangement

We program the output part to a '1' bit on the channel corresponding to the first wire, and this causes the motor to advance exactly one sixty-degree step. For the next step the previous '1' bit is zeroed and the channel corresponding to the next channel changed to '1', and so on, taking the three wires in cyclic order. For reversing, we perform the cycle in reverse order.

Usually we program the output part by means of a 'POKE' command in BASIC, and in fact the rather slow operation of BASIC is particularly suited to motor operation. It may be necessary to insert a time-wasting routine after each step to let the mechanical movements catch up with the computer.

Preferably a sub-routine in BASIC would be written to perform three steps, making a half-turn in all, with suitable delay between steps. This saves having to keep track of which wire is next at the subsequent moves.

The actual number of steps to move from say X=1296 to X=1299 would depend on the screw threads and the units of measurements. It would be preferable to choose the threads to correspond to some convenient length such as three steps to one tenth of a millimetre.

For simplicity we can dispense with the general commands and rate commands and simply operate with a series of X and Y co-ordinates. These can be stored in arrays or, if too numerous, on a disk or M/T store. For circular, elliptic or parabolic arcs the computer can be made to calculate the co-ordinates of points at small intervals along the arcs and store them in an array or file prior to the actual run of the N/C program.

Assuming that the co-ordinates are in absolute terms (ie that they represent the actual co-ordinate and not the increment from the previous point) the sequence of the programme would be:-

(a) Find the difference between the next co-ordinate and the present co-ordinate and calculate the number of steps required to reach the new X co-ordinate.

(b) Calculate the appropriate change of Y for the new X co-ordinate and hence the gradient.

(c) Move one step in X and decrease the count of X steps.

(d) Calculate from the gradient the new value of Y corresponding to the new X value and move this number of steps in the Y direction.

(e) Go to (c) unless X count is zero. If zero, go to (a).

The input X, Y values can be in absolute terms or increments.

The apparatus can either be created to resemble an automatic lathe in appearance, or arranged for simplicity and easy demonstration. A suggested instance of the latter type follows.

In Fig 2, C is a platform (on wheels for reduction of friction) moved in the X direction by stepping motor A using a screw thread engaging two nuts fixed to the platform. A smaller platform D is moved in the Y direction by motor B, both D and B being on Platform C. The workpiece is rotated by a mains motor arranged on the bench in front of C. An ordinary electric drill could provide both motor and chuck, and could be supported by a clamp on the bench in a horizontal position. Wax candles can be held directly, plasticine supported by a wooden spindle. A motor from an old gramophone would provide a slow-turning motive power for better demonstration of movements.

If, instead of a cutting tool, a heated knitting needle was used, this could 'burn' the paraffin wax in similar fashion to an arc welding torch.

A similar arrangement, but with B controlling a drill bit, directly underneath it, could be used to drill a line-pattern of holes very precisely. (This is a common use of N/C in industry)

The X and Y co-ordinates can be stored in two arrays and the machine code program written simply as two columns of figures.

(2) An extension of (1) to a model 'milling machine' necessitates a third motor to work in the Z direction to control the depth of cut.

This is most easily done by having the platform D in Fig 2 made large enough to support the workpiece, and having the Z motor operating the tool fixed to a stand on the bench, so that the workpiece clamped to D moves in the X and Y directions and the Z motor drives the tool to the required depth.

A suitable demonstration might use a hot needle as the tool so that a flat sheet of wax or waxed metal can be 'engraved' with a computer-controlled design. This has the advantage of requiring less force and giving an anaiogy with arc-cutting.

If the tool took the form of one of the small electric drills now available, it might be feasible to do useful hole-boring jobs with the model (an N/C tool can be programmed to patterns of holes).

These models are ideal for bringing school technical departments into the computing field, as firstly machine tools are in their province, and secondly they are the obvious people to make them.

(3) Model Graph Plotter

This can be arranged to copy closely the commercial models, or it can be arranged like (1) with the Z motor replaced by a relay to raise and lower the pencil.

Another arrangement is to have one motor turning an arm in the plane of the paper and another doing radial movements on the arm, giving polar co-ordinates.

(4) Computer-controlled Robot Arm

(a) Many of the useful 'robots' in use in industry have nothing in common with the popular idea of a robot. The most common one is simply an arm with a clamp on the end which swings round, clamps on to a product at the end of a conveyer, swings round to a pre-set place on a tool platform, and releases the product, ie it moves a product from one process to another when the next machine is ready.

If constructed of light materials with well lubricated parts, the small stepping motors could operate a model of such a robot. Three motors, or two motors and a relay would be required. One motor for bearing, one for elevation and either a motor or relay for the clamp.

The exact sequence and timing would be found by trial and error in finding the number of steps for each part of the movement.

(b) Two stepping motors powering a toy car - one for motive power and one for steering, would show the possibilities of programmed vehicle movements. In addition, stepping motors could be used to operate the controls of a radio-controlled boat or plane. In these applications, of course, exact repeatability of paths would not be possible because of changes in the environment, but this could be used to demonstrate the need for feedback of positional information, another aspect of computer control though normally much more sophisticated.

(5) 'General Duties'

Stepping motors can be used for various 'odd jobs' like turning taps on and off, operating mechanical switches, operating railway points etc.

(6) Small Model of Production Line

To demonstrate that the computer can control, accurately process time and position, a small model of a production line can be made using a stepping motor to drive a long threaded rod on which are nuts attached to a light platform on wheels.

Fig 3

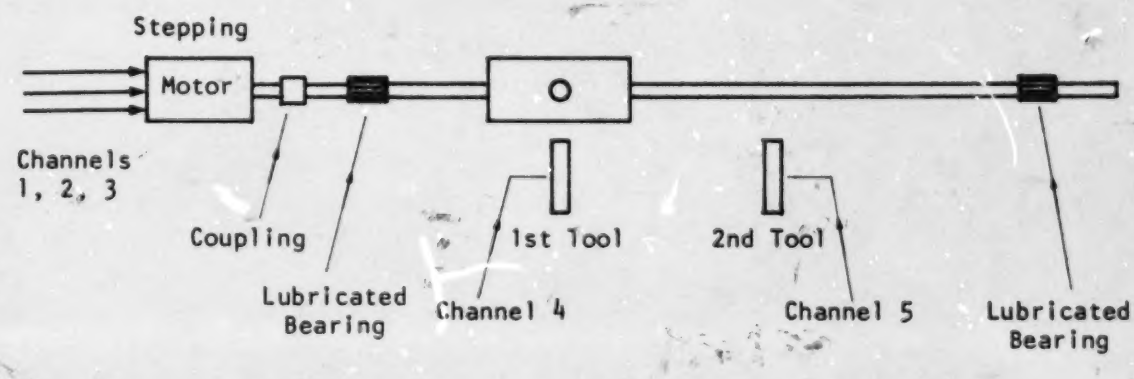
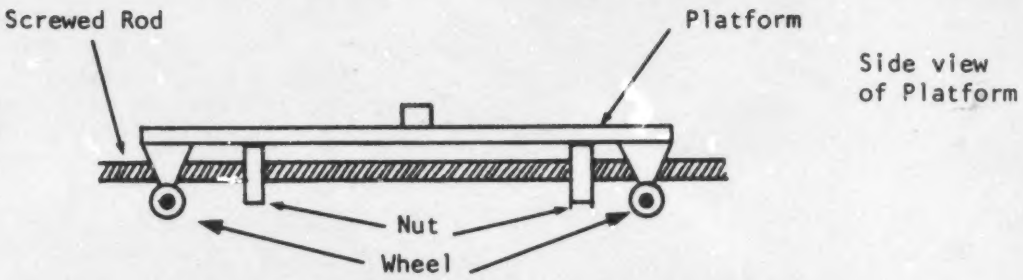


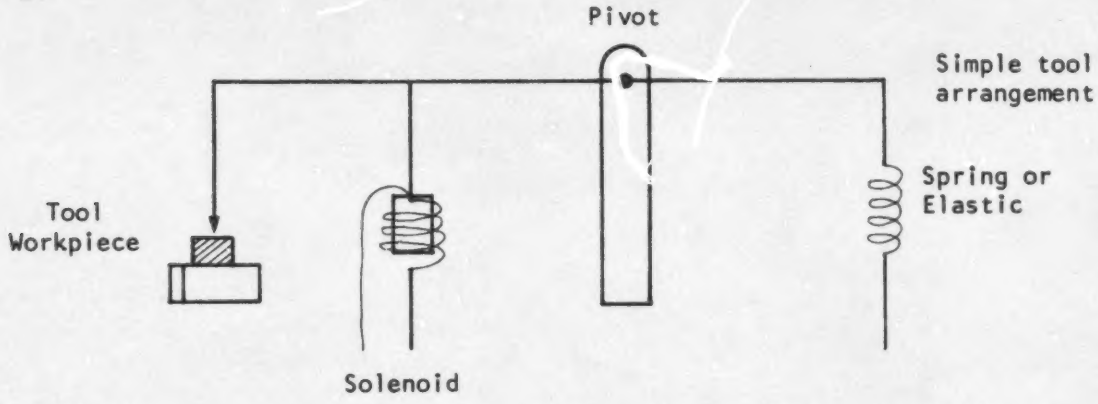
Fig 4



A series of relays and/or solenoids work simple 'tools' at various distances along the rod. An object (eg a small blob of plasticine) is placed on the platform and the program moves the platform to each 'tool' in turn for a prescribed time and moves on.

The 'tools' need not be very elaborate, for example, a simple arm activated by a solenoid, with a spring at one end and a pointed piece of wire (piercing tool) or a smaller piece of iron (hammer) at the other.

Fig 5



The solenoids can be bought (see radio spares magazines) or home made. Other tools could be 'fans' driven by one of the small inexpensive motors now available or a solenoid-operated ram to push the workpiece off the platform at the end (or even a hooter to signify that the work is finished!)

By making the platform longer, several successive workpieces can be operated on simultaneously.

Three output channels would be available for the stepping motor, allowing another five channels for the solenoids etc. A convenient coupling from motor to rod can be made with a small piece of pressure tubing. The channels from the computer interface will, of course, be provided with the usual opto-isolators and amplifiers, remembering that multiple units are available with 4 opto-isolators and 7 darlington drivers.

In action, the computer will activate the stepping motor to activate the platform a set amount (to bring the workpiece under the tool). The first tool will then be activated by a 1-bit in the appropriate channel, a suitable delay introduced before the tool is re-activated after restoring the 0-bit. After a set number of repetitions the stepping motor moves the platform to the next tool.

C. PROJECTS USING ANALOG-DIGITAL INTERFACES

Most physical quantities can be measured electrically and these quantities and their electrical equivalents are continuous or 'analog' quantities, which must be converted to digital form for use by the computer. Most of the 'interfaces' to do this conversion supplied or recommended by micro-computer manufacturers are of an elaborate type taking sixteen channels of information at once and some of them capable of two-way analog-digital and digital-analog operation. They cost from £160 to £300. It may be that in the future school physics laboratories will be supplied with these to bring their experiments into line with those in industry, but in the meantime a start can be made with single-channel A/D devices costing about £6 or less. Each of these will deal with one measurement and will require eight pins of the user part on the computer. The multi-channel devices can be programmed to switch channels so that eight pins will suffice for sixteen channels of information.

(1) Preliminary Projects for Experience

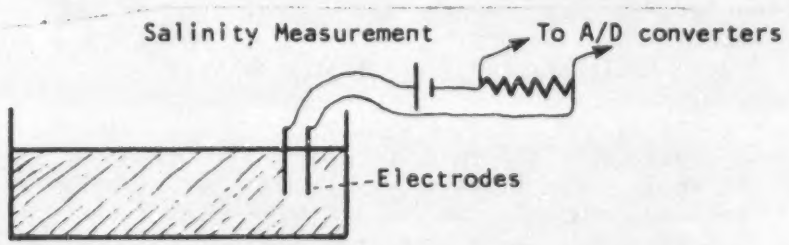
(a) Make a digital thermometer using a thermistor (eg Fenwell GA 44 P2 glass probe type) attached to the user port via the A/D converter and use a computer program to convert the digital input to a correct calibrated temperature for display on the screen. The A/D converters are claimed to be linear within about two per cent, but it would be a good exercise in mathematics to calibrate the instrument precisely.

NOTE: The Apple computer with a games connector can be directly connected to a thermistor - see article in the Journal MICRO of March 1980.

(b) Make a digital weighing device using a strain gauge attached to a steel strip, with the load in a small box on the end of the strip. Since the voltages from the gauge are very small they must be amplified to a reasonable level within 0 to 5 volts for input to the A/D converter. As the digital result has to be calibrated by the computer program the design of the amplifier is not critical so long as the output is not over the safe level for the A/D device. Calibration can be done by putting a series of weights on and noting the digital results. A conversion function can then be found to give the true weights on the screen.

(c) Make a digital salinity meter consisting of a battery circuit where current flows through the fluid being tested via two electrodes. The input to the A/D converter would be taken from across a resistor in series with the electrodes. If gassing on the electrodes proved troublesome, a low voltage A/C could be used in conjunction with a rectifier chip (which costs only 75p).

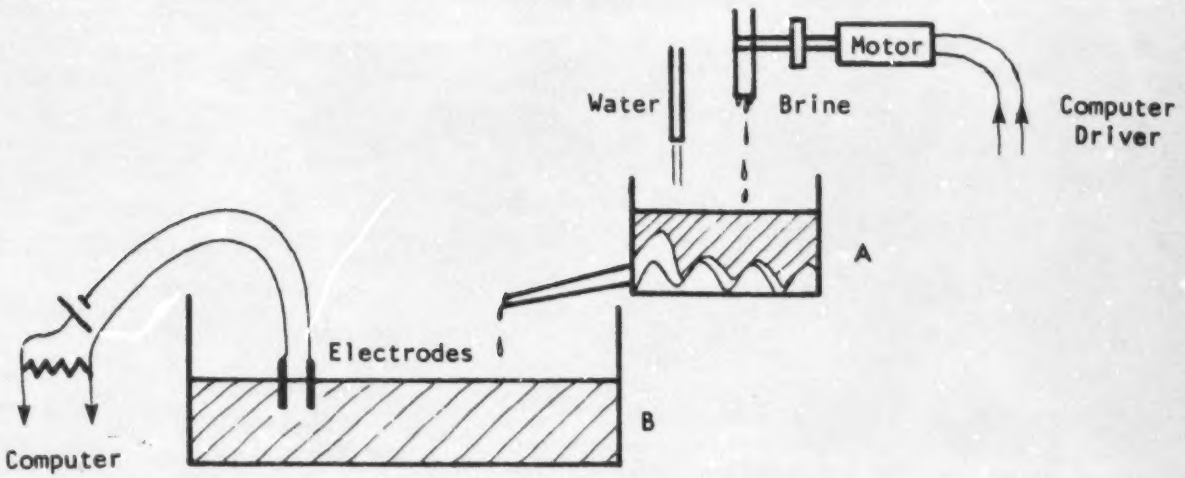
Fig 6



(2) Simulation of a Chemical Engineering Process

To control the salinity of a flowing body of water. The devices used are an A/D converter for salinity measurement and a stepping motor to control input of saline solution.

Fig 7



In Fig 7 the mixer tank A has two inputs:-

ordinary tap water flowing at a brisk rate, and

salt water at a slow drip rate.

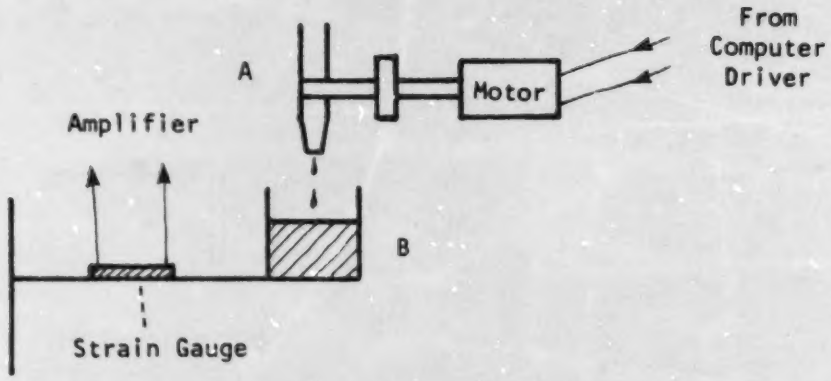
The action of the flow on the rough bottom (broken glass etc) of the tank mixes the inputs. The outflow from tank A goes to tank B which is larger. A salinity measuring device, as in 1(c), has its electrodes in tank B. When the salinity rises above a set value the computer causes the stepping motor to turn down the salt drip rate by turning a tap. The motor can be connected to the tap by a belt-drive so that say ten steps of the motor represent from full on to full off. Slippage of the belt is not important here as there is feedback of information on salinity. Conversely if the salt level is too low the motor will turn up the tap level. The computer can allow an interval to elapse before the next adjustment to allow for the time lag in the flow. If the computer does not have a clock system this could be done by inserting a lengthy program loop. It should be noted, however, that the mixing tank, A, should be small compared to tank B, otherwise the system will have serious oscillations. The mathematics of the control mechanism is of some interest. Some experimentation is clearly necessary.

(3) Simulation of a Production-line Automatic Weighing

In Fig 8, the tap A controlled by a stepping motor allows liquid to run out into a container B standing on the weighing platform of a weighing device, as in 1(b). The tap is turned on by the computer and shut off when the correct weight has flowed in.

Fig 8

Production-line Weighing



For sand or other more solid materials, the tap would be replaced by a shutter operated by a pneumatic relay. This would be more true-to-life, but these shutters operate at a high pressure and might be dangerous in schools even if the compressor could be afforded. The relay might be replaced by a stepping motor opening a shutter against a spring which would snap back when the current to the motor was shut off (by programming zeros on all three motor channels).

The process could be completed by a simple conveyer-belt system operated by a stepping motor which would move the next container an exact distance to bring it under the tap (or possibly a robot to move one container and replace it with another).

(4) Automatic Physics Experiment (typical of instrumentation in industry)

Combining 1(a) with the measurement of a current through a resistance wire we can get the computer to log the data for an experiment to study the variation of resistance with temperature. Two analog-digital converters would be used, one for temperature measurements and one for voltage across the resistance wire. The computer can give the results in a printed table or as a graph, depending on the facilities.

D. PROJECTS USING SIMPLE SWITCHES

If many projects involving switches are to be undertaken, or any project involves many switches, it might be advisable to purchase a standard interface giving 12 channels or so from switches (about £60 for PET).

Otherwise if the voltages are suitable the switches can be individually connected through a gate transistor (about 50p).

(1) Preliminary Experiment using Microcomputer as a Counter

A special switch consisting of two wires bared over say two inches of their lengths with rubber bands separating them. The switch, in series with a resistor to limit the current, is laid on a sloping board and connected via a 6 volt battery to the computer interface. When balls are rolled down the slope they create a momentary contact which in effect creates a '1' bit input to the

interface. The computer is programmed to read the word containing this input, test for a '1' bit in the appropriate channel, and add a '1' to a counter if successful, displaying the current total on the screen. The computer should be able to deal with quite a rapid succession of balls. A similar system is used on road traffic counts.

A beam-interruption system with a photo-diode can be used for a similar purpose. This is used in production line counts etc, as a replacement for the older mechanical counters in cases where a computer is being used for control.

(2) Traffic Light Control

We can set up a miniature traffic light system controlling a 'cross-roads'. The actual switching can be mechanised, controlled by a relay or stepping motor, and the interval allowed for the various roads can be altered to give more time for the roads currently showing most traffic, as measured by a device as in (1). More sophistication can be introduced with experience. The actual switching can be electronic, but this might require more I/O channels than are available on the computer.

(3) Production Monitor for using Individual Operator Switches

Instead of individual operators and management inputting individual numbers on the central keyboard, we can make the operation more realistic, as follows:-

> Each operator will have a switch connected to a channel of the user interface via a transistor circuit as previously described. One channel will be for (human) clock input, as the computer's own timing will be too short in timescale if no clock is fitted. Another will be reserved for management, and two more for difficult types of stoppage. Thus only four operators will take part, plus a timer and a manager. For computers already available with a user interface the extra expense for switches and transistors would be about £10 or less. The operator could be remote from the computer. Switches would be of a type giving a second or so of contact.

E. IMPLEMENTATION OF SIMPLE SWITCH EXPERIMENTS (PET)

The implementation of such experiments, using the ON or OFF position of switches to put information into the computer, depends on the particular machine being used, and the hardware of the microcomputer has to be studied. In general, if the switch is connected to the input-output port via a logic gate and voltages do not exceed the working level in the computer, eg about 5 volts, no harm will come from experimenting. We use the PET to illustrate the general method.

In the PET if we POKE the address 59459 with the value zero, all the channels on the input-output port are scheduled as inputs. In this state the port register 59471 has no value fixed by the computer and whatever value is given to it by the program rapidly drifts up to the value 255 (ie all 1's).

If the least significant channel is connected to ground, this bit is momentarily reduced to 0 and the register then contains 254. All other bits can be zeroed in the same way. As long as the channels are scheduled as inputs, they can be directly connected to ground. For safety it is better to input a 0 signal via a gate triggered by the switch being used.

Example: To time an object rolling down a slope under gravity.

Arrange that the object (eg ball bearing) triggers a switch as it begins to roll and again later at the end of the run. In each case the closing switch connects the channel 1 to ground and thus reduces the count to 254 momentarily. The variable TI keeps a count of time in sixtieths of a second.

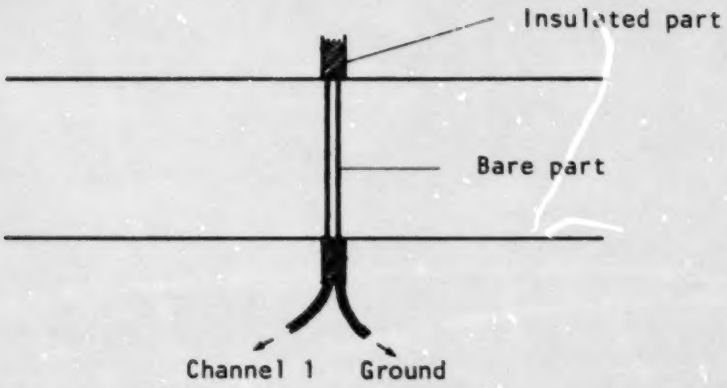
```
 10  POKE 59459,0
 20  PRINT "START BALL ROLLING"
 30  IF PEEK (59471) < 255 GO TO 40
 35  GO TO 30
 40  T = TI
 50  POKE 59471,255
 60  IF PEEK (59471) <255 THEN 60
 70  IF PEEK (59471) <255 GO TO 80
 75  GO TO 70
 80  R = TI
 90  PRINT "TIME OF ROLL =    ", (R-T)/60
100  END
```

The program holds at statement 30 until the first switch is momentarily closed, when the time T is noted. The value 255 will be gradually restored but to hasten the process we can POKE in the value 255. To ensure that the value is actually present we can hold at statement 60 until the value 255 is present (it takes only a few micro-seconds). We then halt at 70 until the second switch is closed. The computer then prints the roll time in seconds.

Similarly, to study acceleration under gravity, we can have a series of switches at equal distances and observe the times of each.

The switches can be optical or mechanical. Optical switches are useful, for example, in pendulum experiments. A simple mechanical switch for the ball-rolling experiment could consist of two pieces of wire, partly bared, stretched across the board on which the ball is rolling, the wires being adjacent and only kept electrically separate by the tension. The ball, in rolling over the wires, causes a momentary contact. (Fig 9)

Fig 9



A similar arrangement can be used to count the number of objects passing along the slope in a given time (a parallel to counting on a production line).

Use of Switches with Relays. In addition to the stepping motor for precise control of machinery movements, we can also switch on an ordinary DC or AC electric motor by a relay and switch it off by another relay when a small switch is tripped by some moving part, or when a count has reached a certain figure.

We could, for example, start a motor with a relay, from a computer signal, arrange for a moving part of the driven mechanism to give a switch signal every revolution, and use the relay to shut off the motor after a set number of revolutions. This gives another approach to exact movements, though one less accurate than the stepping motor. It has the advantage however that ordinary DC or AC motors can be used, with higher efficiency.

There are many mechanical and solid-state relays, and optical switches of all types, described in the catalogues, and there should be no difficulty in choosing a suitable type.

CHAPTER 3 : SOME TECHNICALITIES

INTRODUCTION

In this concluding chapter, some brief introductory comments are given on a few aspects of the new technology. It is hoped that these will be of use to teachers who are interested in developing work in this area.

Electronic devices are subject to a very rapid rate of development so that to keep abreast of current technology one must read the appropriate journals.

General principles alter more slowly and it is these that are emphasised (very briefly) here. It will be noticed that the examples which are given are for the PET machine. This is largely because this machine is well-documented and has a standard fitting, a user input-output panel to which various devices can be connected easily. With most other computers, a suitable input-output board has to be purchased as an extra (usually about £120), in some cases providing multiple A/D conversion as well. The newer Apple machines have a games attachment which gives some A/D conversion and some digital input facilities. Although one can usually attach devices to a computer which has no specific input-output panel, this is not to be recommended unless one is very expert; the proper extension boards should be acquired.

Although there is no great lack of books on the topics mentioned, most are not suitable for senior pupils or for teachers who are acquiring skills in this area.* There would seem to be a need for a knowledgeable group of teachers to draw up some working notes for use in school and specific to the microcomputers used at school.

* However mention can be made of:

"Understanding Digital Electronics", G McWhirter
(Texas Instruments Learning Centre)

"Computers: applications and implications", P Weston & M Roberts
(Harrap, London)

Also, publications of the Microelectronics Educational Development Centre, Paisley College, Paisley.

PART A : STEPPING MOTORS AND THEIR OPERATION

1. STEPPING MOTORS

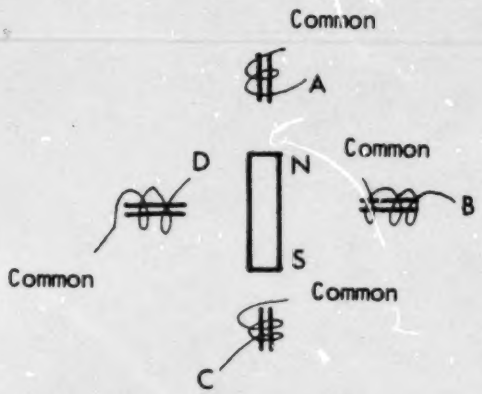
Stepping motors convert '1' bits at the output port of the computer into physical rotations, so that a given number in the computer can be converted to a corresponding number of rotation steps, ie the computer can move a physical object by a precise amount. The computer signals must be greatly amplified and otherwise made suitable for the motor by a 'driver unit' which may be an ordinary powerful amplifier, or may be a special type like a darlington driver.

Small ex-service and fairly inexpensive motors are currently available for 12 volt operation. One cannot expect a large torque from these motors; they are suitable mainly for screw drives where torques can be small.

Large motors of this type are used in industry. For heavy machinery they are used as control devices for heavy hydraulic motors.

The operation of the simplest motor is shown in Diagram A.

DIAGRAM A



Four wires carrying stepping current, one common lead.

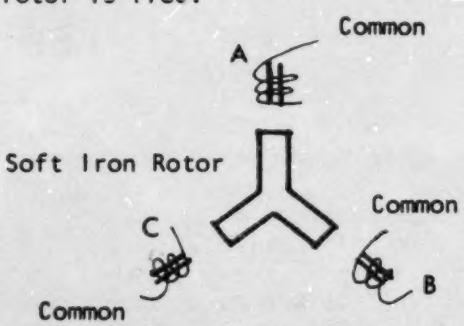
This gives 90° step.

The rotor is a permanent magnet, and there are four coils A, B, C, D.

If the rotor is initially opposite A, and B is energised, the rotor will rotate to be opposite B and hold there. If C is then energised and B switched off, the rotor will rotate to C, and so on. Note that the rotor is held firmly in place at each step until the next change occurs.

Another type is shown in Diagram B. In this type the rotor is of soft iron, with little or no permanent magnetism. Again the coils A, B and C are energised in turn and the rotor follows the resulting rotating magnetic field. In this case there is little force keeping the rotor in position if there is no current, so that it is desirable to time the switch-off of one pole when the next is switched on. If all are switched off the rotor is free.

DIAGRAM B



Three wires carrying stepping current, one common lead.

This gives 120° step.

2. USE OF STEPPING MOTORS

The stepping motors available on the general market are all of the soft iron armature type, because of the smaller steps possible with these and probably also because of lower manufacturing costs. The smaller sizes are liable to have difficulties in operation, one of which is that the armature tends to retain its magnetism, particularly at slow speeds, and the action becomes erratic. This is liable to happen with the AEG G 021 motors given to schools by the MET Group. It can be overcome by applying a high-frequency signal between pin 5 and each of pins 2, 4, 6 and 9 (about 100 Kilohertz) at very low power. The following comments refer specifically to those motors which are more complex than most others.

The motors, however, operate reasonably well at moderate speeds. Some of them are liable to develop bad contacts at the lower end of the pins, probably due to overheating on soldering of the wires from the driver.

These motors require 3 lines from the computer output port (through the driver) and one 'common' lead from the negative end of the 12 volt supply.

Pins 1, 3 and 8 are the 'live' pins and pin 7 is the 'common' pin.

The 'live' pins are activated in turn by arranging a '1' bit successively on channels 1, 2 and 3 of the output port, ie by putting the numbers 1, 2 and 4 successively on the port address. The output from the port is amplified in the same way as for relays, one amplifier channel for each of the three pins, to give about 0.5 amps. At each step the rotor advances 60°, so that the complete cycle of 1st, 2nd and 3rd channels gives a half-turn. To reverse the direction we simply reverse the sequence, ie pins 3, 2, 1 and number 4, 2, 1 on the output register address.

We can control a second motor similarly by using channels 4, 5 and 6, leaving two channels spare for relays etc.

More reliable motors are frequently advertised in the electronics journals for £4, £12 etc, and most of these have smaller step sizes. Some of them require only two 'live' wires and 'base' wire. One 'live' wire indicates the direction of rotation and the other indicates a step. (It would be perfectly possible to build a driving unit with a counter chip and some logic gates to make any stepping motor rotate a given number of steps without further prompting by the main program.)

3. PROGRAMMING STEPPING MOTORS (assuming a 3-channel type as in 2 above)

The successive coils of the motor are energised in turn, by putting a '1' bit on the corresponding channel of the output port. This in turn is accomplished by putting a '1' bit on the corresponding bit position of the output register address. This address must be known for the particular machine being used. It is address 59471 for PET machines,

which we take as an example. In the PET we have to make all channels into outputs by putting a 1 on all channels of another address (59459), but this is not required if there are separate input and output channels.

Putting a number 1 (ie 2^0) on the output register puts a ' on the least significant channel makes the 1st channel live, 2 (ie 2^1) makes the second channel live, 4 (ie 2^2) makes the third channel live, and so on to 128 (2^7) which energises the most significant channel.

Because the computer works very rapidly, even in BASIC, we put some delay in the program to enable the motor to respond.

```
BASIC Program (PET)
10 POKE 59459,255   (Makes all channels outputs)
20 FOR K=1 TO 100
30 FOR L=1 TO   5
40 POKE 59471,1     (First channel energised)
50 NEXT L
60 FOR L=1 TO 5
70 POKE 59471,2     (Second channel energised)
80 NEXT L
90 FOR L=1 TO 5
100 POKE 59471,4    (Third channel energised)
110 NEXT L          (Another half turn)
120 NEXT K
130 END
```

This assumes a three channel 60^o step motor connected to the three least significant bit lines. The L loops are for delay purposes and the limits of L can be varied to suit the conditions of motor running. As an alternative, instead of repeating the POKE statement we can introduce an irrelevant program step:-

```
40 POKE 59471,1
50 PRINT "CALCULATOR"
60 POKE 59471,2   etc.
```

One step of the motor is produced as each channel is energised, and each K value gives here one half-turn (180^o). In this case the program gives 100 of these.

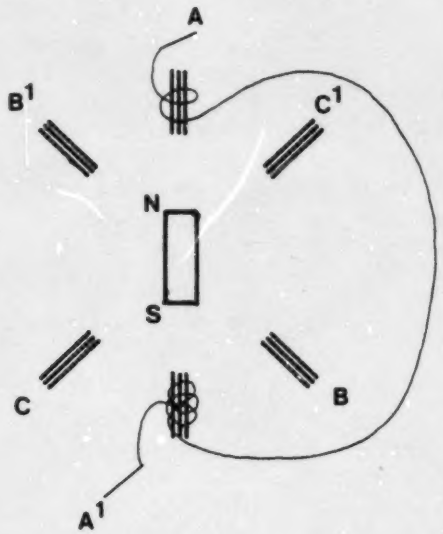
In PET the output register address is 59471, and the other address 59459 is such that all 1 bits in it make the corresponding channels into outputs and 0 bits make corresponding channels into inputs.

Most microcomputers have separate input and output registers with separate connecting pins.

4. A DO-IT-YOURSELF STEPPING MOTOR

Because of the rather complex and obscure action of the commercially made stepping motors, it is worthwhile to make a home-made one of

traditional construction which is open to view. The simplest one is probably one with a small bar magnet as rotor and three pairs of coils at 120° to each other.



Wires at A, B and C are connected to the computer channels via the usual driver circuits and A^1, B^1 and C^1 are connected to base voltage. This gives 120° steps. The pairs of coils are of course so wound that north and south poles are produced at opposite ends of the diameter of the motor.

The main difficulty is the mechanical one of mounting the magnet suitably (they are too tough to bore). A notch cut in a plastic rod or axle from a child's toy could be used to hold the magnet (cemented in), or the magnet inbedded in a 'polyfilla' cylinder. The coils can be mounted on a wooden board which would also hold one bearing for the rotor, the other being held by an arm screwed to the board. In this way pupils can see the magnet stopping at successive poles as the computer programs the coils to be energised.

NOTE: A diode must be connected across each coil to damp out the (sometimes high voltage) surges which occur when the current in the coil is cut off. The diodes, of course, are connected so that they have a high resistance to the ordinary coil current and short-circuit the reverse surge currents.

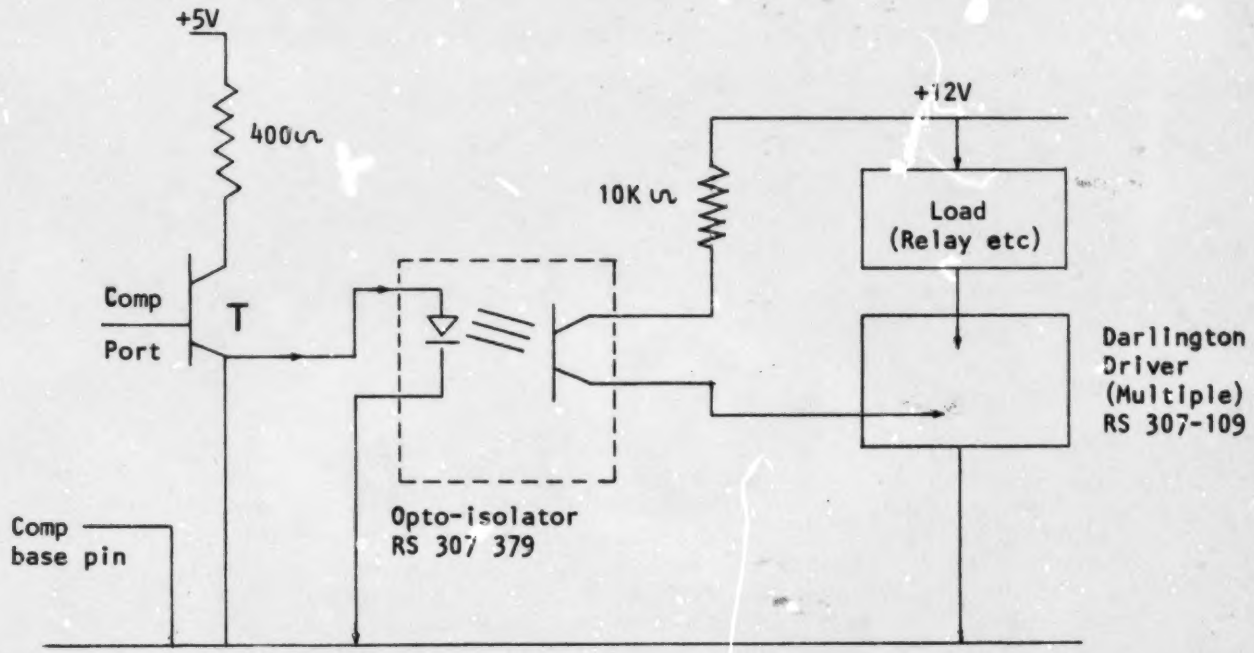
The coils should be of a large number of turns of fine insulated wire, to get a suitably high impedance for the circuit. Since the idea is to use materials at hand, it will be necessary to experiment a little to get the best results.

5. DRIVER CIRCUITS FOR MOTORS AND RELAYS

We require to boost the current of a few milliamps from the computer output to about 0.5 amps in an inexpensive manner and to protect the computer against short-circuiting and surges of current coming from the connected apparatus. (Coils carrying a current have a reverse current, sometimes of high voltage induced in them when the main current is cut off.)

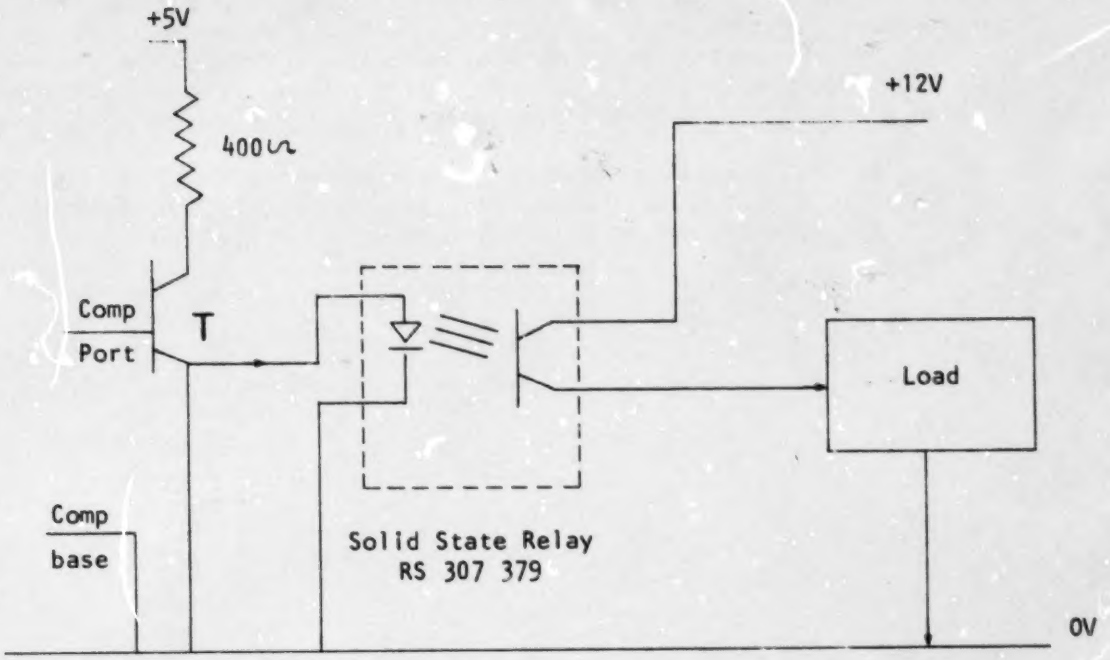
Many variations of driving circuits are possible, and there is room for experiment to find the least expensive and most robust. The following are only two possible variants that have been tried successfully.

(a)



This uses a transistor stage between the computer and opto-isolator, to provide the right input impedance and boost the signal a little. The opto-isolator given can be replaced with a darlington type RS 307-963 which will give a gain in energy. Total cost is about £5, but if several channels are required multiple isolators (usually 4 in one unit) and multiple darlingtons can be used to make a compact unit for the driving system and save costs considerably. If the channels are all to be busy the heat dissipation from the multiple units must be considered. Almost any available transistor will do for T, though the resistor may need adjusting with some types.

(b)



In this case the ordinary opto-isolator is replaced by a solid state relay which works on the same principle but can produce very large currents at output, and handle up to 1.5 amps and mains a.c. voltages. When no signal is input the relay has a high impedance and when a signal is input impedance falls to a low value, causing the load to be connected to the supply. Whether a resister is required in the load circuit depends on the nature of the load and its impedance. Normally motor coils do not require a resistor (only a diode!) at 12 volts input.

If the computer signals are very weak a further transistor stage, or a darlington isolator can be used before the relay to boost the signal and give some further protection.

PART B : INPUT AND OUTPUT SWITCH SIGNALS

1. USING THE COMPUTER TO SWITCH DEVICES ON AND OFF

The solid state relay connected as described on page 28 will switch devices on by simply receiving a '1' bit from the computer output - the device being the load.

Either of the devices on pages 27 and 28 can be used also to operate a solenoid which in turn can operate a mechanical switch or other moving part such as a model railway point. If a mechanical switch is used, it is convenient for it to be of the type where one movement switches ON and a second identical movement switches OFF. The computer can then, after switching ON, turn its attention to other things which may require a zero on that channel.

Example (PET): To switch on a lamp on channel 1, switching off at the end of the program.

```
 10 POKE 59459, 255              (All channels output)
 20 POKE 59471, 1                (Channel 1 energised)
 30 PRINT "LAMP ON"              (Delay to give time for mechanical action)
 40 POKE 59471, 0                (Channel 1 de-energised)
 50 POKE 59471, 2                (Channel 2 energised)
    .
    .
    .                            Any statements not putting 1 in channel 1
    .
    .
    .
200 POKE 59471, 1                (Channel 1 energised)
210 PRINT "LAMP OFF"             (Delay)
220 END
```

This assumes that the switch is such that successive operations give ON then OFF.

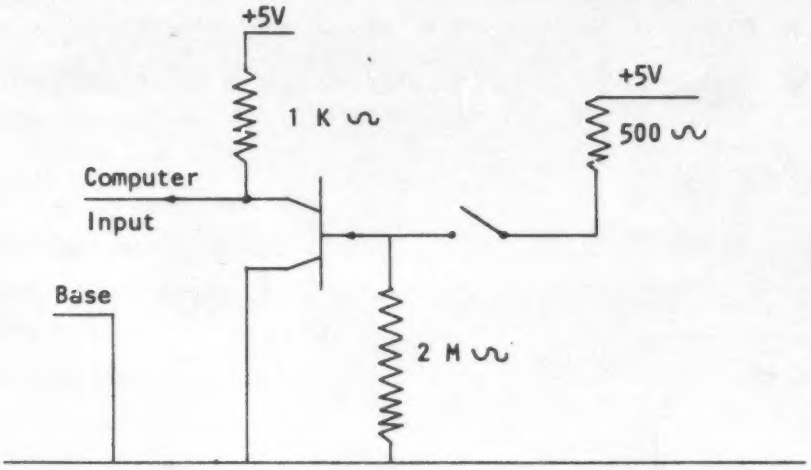
If the solid state relay is used we can keep the'1'bit on channel 1 until the light is due to go off, ie whatever alterations to the output register are made, we arrange to keep 1 in channel 1, eg statement 50 would be

```
 50 POKE 59471, 3                (Energising 1 and 2 channels)
```

2. INPUT SWITCHING

When we want to indicate a simple ON-OFF message to the computer (for example to indicate the passage of an object in a counting mechanism or the completion of a job in a production monitor program) we can input 0 or 1 on an input channel. The signal has to persist long enough to ensure that the computer has time to absorb the information.

If the computer is in fact kept in a state of search for the information, and not busy doing something else, it is sufficient to use a toggle switch, as the tenth of a second, or so, during which the switch is closed is long compared to the search time. Otherwise we have to arrange for the input to 'interrupt' the program and this involves more complex programming, usually in Assembler.



When the switch is open the input line is held at +5 volts. When the switch is closed, the transistor conducts and the input is effectively reduced to near 0 volts. The input register in that channel is then changed from 1 to 0.

Example (PET): Four operators are inputting, to a production monitor program, on channels 1 to 4. Management inputs on channel 5.

```
10  A=0
20  B=0
30  C=0
40  D=0
50  POKE 59459, 0                          (All channels input)
60  POKE 59471, 255                        (All channels of register hold 1 bit)
70  IF PEEK (59471) = 255 THEN 70          (Waits for input)
80  IF PEEK (59471) = 254 THEN 200         (First channel switched to 0)
90  IF PEEK (59471) = 253 THEN 300         (Second channel switched)
100 IF PEEK (59471) = 251 THEN 400         (Third channel switched)
110 IF PEEK (59471) = 247 THEN 500         (Fourth channel switched)
120 IF PEEK (59471) = 239 THEN 600         (Management input)
```

```
130  IF PEEK (59471) = 223 THEN 700     (PROGRAM END)
140  GO TO 80
200  A = A +1
210  PRINT "OPERATOR A", A
220  GO TO 70
300  B = B +1
310  PRINT "OPERATOR B", B
320  GO TO 70
400  C = C +1
410  PRINT "OPERATOR C", C
420  GO TO 70
500  D = D +1
510  PRINT "OPERATOR D", D
520  GO TO 70
600  PRINT "OUTPUT SUMMARY", A, B, C, D
700  END
```

3. LOGIC GATES

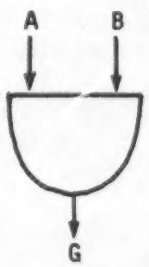
Gates are now usually in the form of specialised chips, but they can be made up of transistor pairs if necessary.

(a) AND Gate

These have two or more inputs and one output. Their property is that all inputs must be 1 for the output to be 1, otherwise output is 0.

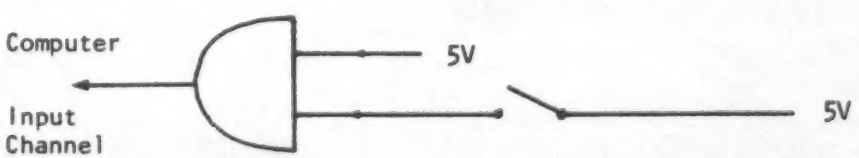
Truth Table

A	B	G
0	0	0
0	1	0
1	0	0
1	1	1



Symbol

We could use an AND gate to input an on-off signal to an input line in a user interface channel.



Input channel held at 0 until switch is closed.

(b) OR Gate

Two or more inputs, one output. Output is 1 if any of the inputs is 1.

Truth Table

A	B	G
0	0	0
1	0	1
0	1	1
1	1	1

We could use an OR gate for input to an interface (as above but with one input permanently earthed and the other switched).

(c) AND Gate

An AND gate followed by an inverter so that the outputs are reversed.

Truth Table

A	B	G
0	0	1
1	0	1
0	1	1
1	1	0

(d) NOR Gate

A NOR gate followed by an inverter. Only if all inputs are zero is the output 1.

Truth Table

A	B	G
0	0	1
0	1	0
1	0	0
1	1	0

(e) NOT Gate or INVERTER

Simply reverses the signal 0 to 1 or 1 to 0.

Truth Table

A	G
1	0
0	1

PART C : ANALOG CONVERSION

1. ANALOG AND DIGITAL NUMBER REPRESENTATION

The computer handles numbers in digital form using the binary scale. The bits in the storage area can be regarded as representing 0 or 1 according to whether there are 0 volts or 5 volts (or whether they are at a low or high magnetic state in the case of magnetic storage devices). All numbers have to be represented by a sufficient number of 0's and 1's. In an analog system numbers are represented by a continuous quantity, eg scale length in a mercury thermometer, or dc voltage in physics measurements such as light intensity or thermo-couple measurements.

Almost any physical measurement is most conveniently represented by electric current, and we wish to be able to feed these measurements directly into a computer to get an instant and accurate response instead of having to read a meter manually and then enter the result on the keyboard, with the delay causing the result to be out of step with other quantities being measured and extra inaccuracy due to reading error.

To enable direct input to be possible we must convert the continuous current variations into digital numbers. Such a device is an Analog/ Digital converter (A/D). Conversely we may wish to output from the computer a direct current signal proportional to a digital number we have in store, for feeding to an experiment or controlling a motor speed for example. This is done by a Digital/Analog converter (D/A).

The D/A is a more basic device, and most A/D machines use a D/A in their working. They require a stable reference voltage supply.

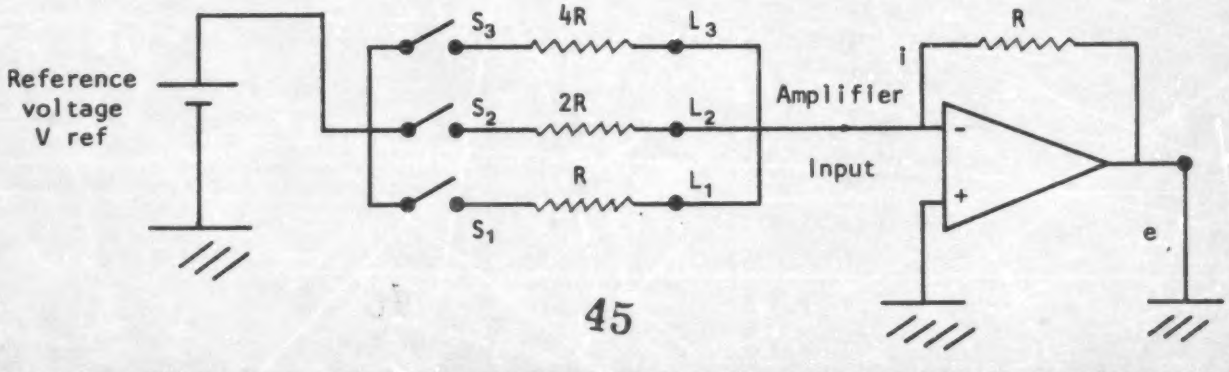
The suppliers of D/A and A/D chips will often supply very good descriptions of their operation, as well as working characteristics.

The chip is quite complex. For example, an A/D chip consists of a multiplexer, A/D converter, control and bus interface arranged on a single chip, with separate power supply (ie separate from the input current being measured). The background study of such a chip might be a good introduction to the pupil of the important world of the dedicated chip industry.

The following is a brief summary of some types of converters in common use.

2. DIGITAL-ANALOG CONVERTERS

For simplicity consider a 3 - digit binary number being converted to an analog voltage.



The total current in the network is the sum of the currents L_1, L_2, L_3.

If we arrange for the switches to be open or closed according to whether the corresponding bit is 0 or 1, then the currents L_1, L_2, L_3, will depend on these bits, and will be in ratio of 4:2:1 if all bits are 1, so that the bits contribute to the total current in relation to the place-value of the bit, ie 2^2, 2^1, 2^0. The circuit equations give

$$\frac{V - e}{R} = S_1 \quad \frac{V \text{ ref}}{R} + S_2 \quad \frac{V \text{ ref}}{2R} + S_3 \quad \frac{V \text{ ref}}{4R}$$

and hence the output voltage e, when a steady state is reached, is given by

$$e = -V \text{ ref } (S_1 + S_2/2 + S_3/4)$$

where S_1, S_2, S_3 are 0 or 1.

Similarly we can extend the network to any number of bits. With microcomputers there are usually 8 bits and hence

$$e = -V \text{ ref } (S_1 + S_2/2 + S_3/4 + S_4/8 + S_5/16 + S_6/32 + S_7/64 + S_8/128).$$

When the number of bits gets very large the quantity in brackets tends to a maximum value of 2 so that we can take as a working rule that V ref should be minus half the maximum value of the output voltage. The switching is easily done by transistor switches, one for each bit. In practice the whole assembly of switches, resistors and amplifiers is contained in one chip.

The characteristics of the device which should be known are:

Resolution, defined as the smallest increment of voltage which can be registered. This obviously depends on the number of bits available in the computer circuit. Usually it will be 1 in 2^8, ie about 15 mV.

Accuracy, is closeness of the output voltage to the theoretical output and is largely dependent on the accurate matching of the resistors in the network.

Linearity, is the extent to which the output remains strictly proportional to the input.

The operational amplifier has the following parameters:-

Slow rate, is the rate with which the output can change in response to a change of input.

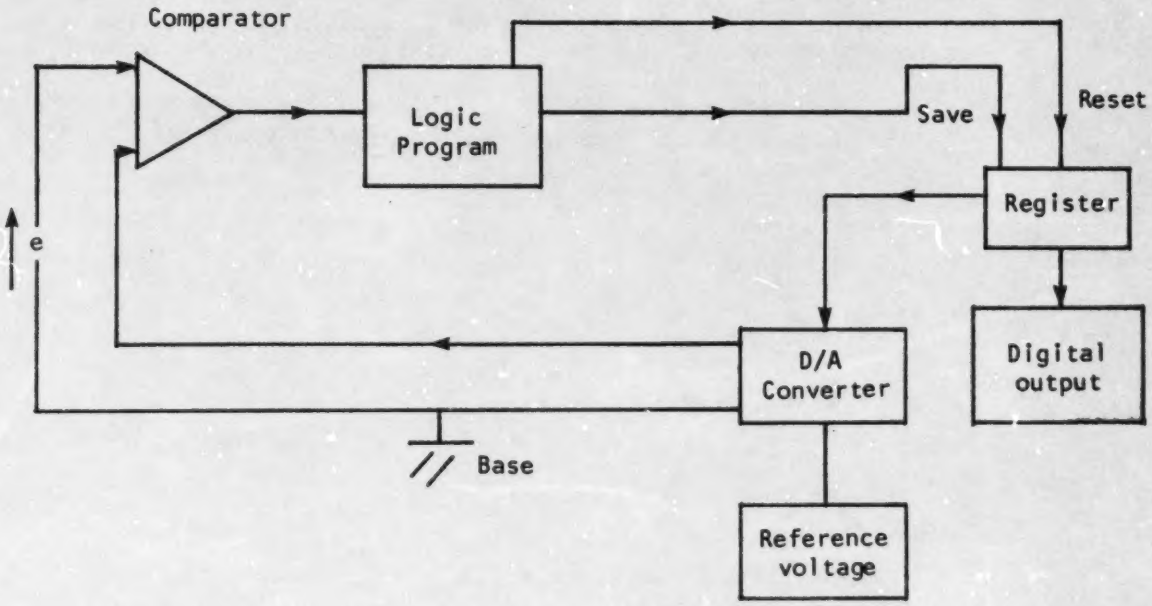
Settling time, is the interval for the output to settle in its new value after a change of input.

Zero offset, is small output voltage present when binary output is zero.

Drift, is the slow change of output voltage due to the effects of temperature on the input stages.

3. ANALOG-DIGITAL CONVERTERS

There are many different types of A/D converters, varying in speed of conversion. The faster types, converting 8 bits in a time between 2 and 30 microseconds, use a D/A converter to provide a variable reference voltage which is compared to the incoming analog voltage and altered until equality is found, when the digital value is the required conversion value.



Starting with the most significant bit, the logic program tries a '1' bit in each successive bit of the D/A converter, whose output is compared to the analog input e as each bit is tried. If the D/A output is larger than e, the 1 is removed from that bit and the next less significant bit is tried. When the output is smaller than e, the '1' bit is retained and the next bit tried. After the least significant bit has been tried, the digital number of the D/A converter is the digital equivalent of the analog input e.

These converters are available as single chips, and in some cases the unit comprises both D/A and A/D converters. The simpler types are available for about £8, and full details of their working characteristics and connections should be obtained from the suppliers.

Note that the digital result of the A/D device is true only for an instant if the analog input is varying, and if several quantities are being read or set, the time elapsed between the reading of the questions must be considered. Where the quantities are varying rapidly, the speed of computer operation is important, and BASIC will probably be too slow, so that ASSEMBLER must be used. However, much interesting work can be done at a relatively slow rate, and schools would probably be better to aim at these relatively slow experiments and concentrate on periodic sampling and a good presentation of results in tabular or graphical form.

Analog output from D/A can be used to set the independent variable in an experiment, eg voltage across a non-linear impedance, but if appreciable currents are involved a linear amplifier will be required. These are normally expensive, but they are now becoming available as companion chips to the D/A units.

4. USING THE ANALOG-DIGITAL SYSTEM

The A/D system is plugged into the input user port of the computer, or, if there is a common input-Output port as in the case of PET, the port is chosen by program to be input on all channels (in PET the command is POKE 59459,0).

There are two ways of using the input; by sampling the input at regular intervals or by sampling continuously with the input of data synchronised with the machine cycles by means of the 'handshake' lines provided on the port. The former is much easier and is probably all that most schools will want to tackle. The method used is fairly standard for all machines although the handshake techniques differ on the various machines.

Example: (for PET, where 59471 is the port address and 59459 is the Data Direction Register which determines whether each channel is input or output).

```
 10  DIM  X(100)
 20  POKE  59459,0
 30  FOR K = 1 TO 100
 40  T = TI                    )
 50  IF TI = T + 60 THEN 50    )   Counts out one second
 60  G = PEEK (59471)              (reads analog input converted to digital)
 70  X (K) = G
 80  NEXT K
100  PRINT "TIME IN SEC", "READING"
110  FOR K = 1 TO 100
120  PRINT K, X(K)
130  END
```

This will read the value of the analog input (which could be the output of a thermistor in a cooling curve experiment), every second and print the table of answers. If a graph facility is available the result could be shown as a curve.

In all A/D operations the analog voltage must not exceed the permitted maximum value (usually 5 volts). Although the value printed in the above program is proportional to the incoming voltage, it is neither equal numerically to that voltage nor to the quantity (eg temperature) it stands for. The result must be modified so that it shows the actual value of the quantity being measured. If the input is linear we can simply make 255 in the computer correspond with the maximum of the quantity being measured, and zero in the computer to zero in the quantity, and calculate the others proportionally. For example, if a temperature reading of 90^{0}C gave 5 volts (maximum) at the computer, and 0^{0}C gave 0 at the computer, then we would amend the program above by altering statement 70 to

```
70  X(K)  =  G x 90/255.
```

This would give the correct answer in degrees. If the input is not a linear function of the quantity being measured (for example if it is being amplified by an amplifier whose linear qualities are suspect) then the system must be calibrated by noting the digital numbers produced

by known values and calculating an interpolation function from them. This function can then be used to convert crude inputs into accurate readings instead of statement 70 above.

The D/A converter can be used to set quantities in the experiment but this gives rise to difficulties:-

the simultaneous reading and input of the result means that either output or input must be stored at least momentarily,

small currents available from D/A mean that in many cases linear amplification is necessary.

Alternatively - and much more simply - the individual output channels can be used to set experimental quantities by successive electronic switching or simply by mechanically switching on circuits. To take a crude case, if we were trying to derive a curve of current against light intensity in a photo-cell, we could use channels 1 to 8 successively to switch on successive lamps, read in the light intensity from a calibrated source, read in the voltage from the photo-cell, and then switch in the next lamp. This procedure of course requires that we can read on different channels. The computer can only deal with one output or input at one time, but if the channels are switched rapidly (in a few milliseconds) the effect can be one of simultaneity. Such units to select channels are part of all multi-channel A/D interfaces such as are supplied by the computer firms, and they can also be used to eliminate all channels and allow the computer to output single-channel digital signals.

It should be noted that owing to the limit of 255 in the 8-bit number the accuracy possibly is limited, but for school use this may be less important than the educational value of the experimental design.

5. SUMMARY

For a school taking up A/D work the sequence should be:-

set up the computer as a weighing machine, as a thermometer, as a digital voltmeter,

devise simple experiments where readings are noted at successive times, eg cooling curves,

combine these with single-channel operation of relays to build automatic weighing machines, etc

before starting on multi-channel work or more elaborate experiments, study the action of your own computer and the A/D unit, and design the experiment carefully with due regard to current size and response times.

In the present state of the art the main object should be to show that the ordinary pupil can use the computer in experiments and that its use is beneficial in getting readings rapidly, calculations very rapidly, with an immediate printing-out of answers.

GLOSSARY

A/D (and D/A)

Conversion of direct-current (Analog) signal representing some measured quantity to a binary number (represented by a series of '1' or '0' pulses) representing the same quantity. For example, temperature is a continuous quantity naturally represented by a direct voltage. To convert this to a number on a television screen we have to change it first into a binary number and then into a decimal number. (D/A is simply the opposite to A/D and converts a computer number into a direct voltage.)

ASSEMBLER

The actual language of the computer, in which the final commands must be written, is composed of binary numbers, eg 1001101. Since this type of command is difficult to work with we use instead two types of user language, which are translated by the computer itself before the commands are obeyed.

a) A language which is simply the machine language in more easily remembered form, eg LDX 1 D0D which might mean 'load into register 1 the number in the store which we have previously agreed to call D0D. This sort of language is ASSEMBLER, and is simply an easy-to-use machine code. Usually one instruction in an assembler language represents one machine-code instruction, and so any program that can be written in machine-code can be written more easily in assembler (low-level language).

b) Since assembler is laborious to write, ie a simple piece of calculation takes many statements, it is convenient to use a 'higher' language like BASIC or FORTRAN which are akin to algebra and which have many time-saving features as well as being easy to learn and are standard for all machines unlike ASSEMBLER.

We can use assembler when we want the program to run specially fast or when we wish to do something not catered for in a high-level language.

DARLINGTON DRIVER

A device for giving a very large pulse of current in response to a small pulse of current.

DEDICATED CHIP

A microchip which has been manufactured with a program into it, to perform some specific task. Its program cannot be altered. It has the advantage that once the program has been prepared, very large quantities can be made cheaply.

R O M	Read-only memory. This is an example of a dedicated chip which is used to store standard programs etc. A special variety called the programmable read-only memory (PROM) can be written with special equipment.
OPTO-ISOLATOR	A combination of a light-emitting diode which gives out light when a current is passed through it and a photo-transistor which conducts current only when light falls on it. It enables signals to be input to a computer without any possibility of surges in the external circuit affecting the computer.